EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) Program evaluated performance of HydroTechnics, Inc. flow sensors in measuring the three-dimensional flow pattern created by operation of the Wasatch Environmental, Inc. (WEI) groundwater circulation well (GCW). The GCW is a dual-screened, in-well air-stripping system designed to remove volatile organic compounds (VOC) from groundwater. Operation of the GCW creates a groundwater flow pattern that forms a three-dimensional regime known as a "circulation cell." EPA's evaluation of the GCW circulation cell involved use of in situ groundwater velocity flow sensors that were developed at Sandia National Laboratories and manufactured by HydroTechnics, Inc.

The HydroTechnics flow sensors are in situ instruments that use a thermal perturbation technique to directly measure the velocity of groundwater flow in unconsolidated, saturated, porous media. The flow sensors differ from other devices that measure groundwater velocity in that they are in direct contact with the unconsolidated aquifer matrix where the flow is to be measured, thereby avoiding borehole effects. The flow sensor is a thin, cylindrical device that is permanently buried at the depth where the velocity of groundwater flow is to be measured. The manufacturer claims that the flow meter can measure groundwater flow in the range is 0.01 to 2.0 feet per day (ft/day) (0.3 to 60.96 centimeter per second [cm/s]) with an error of +/- 0.001 feet (0.03 centimeter). Data collected from the flow sensors include the horizontal and vertical groundwater flow rate as well as groundwater flow direction.

The GCW is a patented system manufactured by WEI and was demonstrated at Cape Canaveral Air Station (CCAS) by the U.S. Air Force Center for Environmental Excellence (AFCEE). AFCEE conducted a comprehensive evaluation of the GCW, including contaminant mass removal rates, groundwater dye tracer studies, and numerical modeling. The results of the AFCEE study can be found in the report entitled "Groundwater Circulation Well Technology Evaluation at Facility 1381, Cape Canaveral Air Station, Florida – Final Report" (Parsons, 2001). The results of the EPA SITE Program demonstration provided additional hydraulic data that are useful in characterizing the GCW circulation cell.

AFCEE managed the overall GCW technology evaluation and was responsible for installation, operation, and optimization of the GCW. EPA was responsible for aquifer hydraulic testing and the installation and

acquisition of data from the HydroTechnics flow sensors. Additionally, the Oregon Graduate Institute conducted dye tracer studies and modeling to evaluate the GCW circulation cell.

EPA's evaluation of the HydroTechnics flow sensors was designed with one primary and four secondary objectives to assess the sensor's ability to detect the groundwater circulation cell established by the GCW. The primary and secondary objectives were evaluated by collecting and interpreting data from seven flow sensors, conducting a series of aquifer hydraulic tests, and collecting GCW operational data during four modes of operation. The four modes of operation include: (1) natural flow conditions, (2) circulation conditions, (3) pump-and-treat testing, and (4) aquifer hydraulic testing (step-drawdown, constant-rate pump testing, and dipole flow testing). Data were collected and analyzed using the methods and procedures presented in the Technology Evaluation Plan/Quality Assurance Project Plan (TEP/QAPP) for the project (Tetra Tech 2000). The data from the groundwater flow sensors yielded valuable information regarding the circulation cell of the GCW. The conclusions of the technology evaluation, as they relate to the demonstration project objectives, include:

Primary Conclusions

P1 Evaluate the flow sensor's ability to detect the horizontal extent of the GCW groundwater circulation cell based on a change in the groundwater velocity criterion of 0.1 foot per day (0.03 meter per day)

- During the GCW circulation operation mode, the groundwater velocities measured by all seven sensors increased by more than 0.1 ft/day, indicating that (1) the sensors were within the circulation cell established by the GCW, and (2) the horizontal extent of groundwater circulation was greater than 15 feet. Furthermore, the groundwater flow direction data suggest that groundwater in the upper portion of the treatment zone generally flows radially away from the GCW and that groundwater in the bottom of the treatment zone generally flows radially towards the GCW. This flow direction data further support the establishment of a circulation cell and that all the flow sensors are within the horizontal extent of groundwater circulation cell.

- The data from the four modes of GCW operation suggest that the flow sensors are responsive to changes in groundwater flow conditions and can be used to help define and evaluate the three-dimensional flow pattern created by the GCW. The immediate response of the sensors to changes in GCW operation suggest that the groundwater circulation cell is established within hours instead of days. Additionally, the velocity data from the flow sensors suggest that the GCW circulation flow was generally constant during operation in the circulation mode.

Secondary Conclusions

S1 Evaluate the reproducibility of the groundwater velocity sensor data

- The reproducibility of the sensors during steady state conditions ranged from 0.1 to 23 percent with an average of 1.9 percent and a standard deviation of 3.8 percent.

S2 Evaluate the three-dimensional groundwater flow surrounding the GCW

- Groundwater flow patterns, as measured by the flow sensors, were documented for each of the four GCW operational modes and are depicted graphically to illustrate general flow patterns in the vicinity of the GCW during each mode of operation.

S3 Document the operating parameters of the GCW

- GCW pumping rate, duration of system operation, and GCW shutdowns were documented for each of the four modes of operation:

GCW Operational Mode	Pumping Rate	Duration of Operation	GCW Shutdowns
Circulation	4 gpm	July 10 – 28, 2000	1 shutdown for mechanical maintenance
Pump and Treat	4 gpm	August 2 – 29, 2000	7 shutdowns for mechanical repairs
Aquifer Hydraulic Testing	Various	September 13 – 19, 2000	None
Natural Conditions	No pumping	GCW not operated	GCW not operated

S4 Document the hydrogeologic characteristics at the demonstration site

- Natural groundwater flow velocities at the CCAS Facility 1381 site are very low, ranging from 0.03 to 0.21 ft/day (0.009 to 0.064 meter/day).

- The conductivity of the aquifer at the Facility 1381 site decreased with depth. Based on aquifer hydraulic test data, the hydraulic conductivity ranges from 43 to 53 ft/day (1.5×10^{-4} to 1.9×10^{-4} cm/s) for the shallow zone (upper 7 feet or 2.1 meters) and 5 to 10 ft/day (1.8×10^{-5} to 3.5×10^{-5} cm/s) for the deeper zone (7 to 25 feet deep or 2.1 to 7.6 meters). The Storativity of the lower aquifer zone ranges from 0.006 to 0.007 and specific yield ranges from 0.06 to 0.09. The average anisotropic ratio (that is, the ratio of horizontal to vertical hydraulic conductivity) is 2.4, based on steady-state dipole flow test interpretation.

Additional findings and observations based on the EPA demonstration of the flow sensors include:

- According to the developer, the flow sensors measure flow in a 3.3 cubic feet [1 cubic meter] area volume immediately surrounding the sensor,) and are subject to local heterogeneities. Complex site hydrogeological conditions may require a large number of flow sensors to adequately define the circulation cell and characterize flow patterns.

- To more fully evaluate the three-dimensional flow surrounding this GCW, additional sensors should have been installed at varying distances and depths from the GCW. Flow sensors should be installed at upgradient, downgradient, and cross-gradient locations at a minimum of three different distances from the GCW. The flow sensors also should be installed at three different depths corresponding to shallow and deep GCW screens as well as in the middle portion of the monitored zone between the two screens. The shallow sensors should be installed a minimum of 5 feet (1.5 meters) below the water table, which would minimize the impact of temperature variations caused by the vadose zone. Only seven sensors were installed for this project because preliminary modeling indicated that the circulation cell would be smaller than what was actually observed in both the upgradient and cross gradient directions.

- HydroTechnics recommends installing the flow sensors with five feet (1.5 meters) of submergence because the shallow portion of the groundwater will heat up during the day, creating a thermal gradient that the sensor measures as water flow. For the EPA demonstration, the shallow sensors were installed with less than 5 feet of submergence because preliminary modeling indicated that there would not be significant flow deeper than 3 feet (1 meter) into the formation. Data from the shallow sensors were successfully corrected by subtracting the background temperature gradient.

- HydroTechnics recommends allowing at minimum of 7 days for the sensors to come to thermal equilibrium. During the EPA demonstration, short-term aquifer tests resulted in large but short-term changes in groundwater flow, that were successfully measured by the flow sensors.

- The cost of a single flow sensor was $2,500. The total cost for the seven sensors, sensor data analysis for a period of 1 year, and installation was $70,000 for this project. Costs at other sites may vary depending on installation depth and subsurface conditions.